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The role of renewable energy in achieving Turkey's INDC

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ABSTRACT

The aim of this study is to analyse impacts of renewable energy sources in achieving Intended Nationally Determined Contribution (INDC) targets of Turkey. INDCs as a part the Paris Agreement are based on national circumstances of countries on climate change. In order to reach the global goal of the Paris Agreement, countries shall monitor, update and upgrade their INDCs. The overall target of Turkish INDC is to reduce its greenhouse gas (GHG) emissions up to 21 per cent from the Business as Usual (BaU) level by 2030. In this study, three scenarios are developed namely Low-INDC, Reference-INDC and High-INDC. These scenarios are used to analyse impacts of utilization of renewable energy on INDC target of Turkey. It is projected that Low-INDC, Reference-INDC and High-INDC can reduce cumulative 566, 511 and 428 million tons of CO_2 emissions respectively. These mitigation amounts could correspondingly provide 32, 29 and 24 per cent of the cumulative emission reduction targets in Turkey's INDC. Total additional costs of Low-INDC, Reference-INDC and High-INDC scenarios are estimated as 12.52, 11.80 and 10.73 billion USD for the period of 2018–2030. Average unit costs of emissions reduction vary between 6.36 and 61.13 USD per reduced ton of CO_2 emissions. In order to guarantee INDC target, Turkey should set new renewable energy targets for the INDC period.

1. Introduction

Global climate change is one of the greatest challenges of our age and tackling climate change urgently requires emissions reduction [1]. Human activities, including greenhouse gas (GHG) emissions, are very likely to cause global climate change [2]. CO_2 emissions as the major contributor of GHG can be reduced by preferring low-carbon technologies, effective energy and resource management and holistic policy approaches including social, environmental and economic dimensions of sustainable development [3–6]. Renewable energy has an important role in the transition to low-carbon development [7,8] and this role has been highlighted in the international climate change agreements such as the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol and the Paris Agreement [9–11]. In 2015, the Paris Agreement was adopted as a new climate agreement based on parties' Intended Nationally Determined Contributions (INDCs). INDCs which reflect each countries' national circumstances, include GHG emissions reduction targets such as quantified emission reduction in absolute or relative terms, intensity or performance based targets and deviation from business as usual (BaU) projections [16]. In line with the global climate policy framework, countries prefer to invest more renewable energy technologies and sources namely hydro, wind, solar, geothermal, etc. to achieve their emission reduction targets [6,12,13]. Besides major global climate policy framework, the transition to zero emission technologies and increasing the share of renewable energy sources in the total energy supply are global trends towards low-carbon development [6]. These trends are also encouraged by the Agenda 2030 and its Sustainable Development Goals (SDGs) particularly the SDG-7 "Ensure access to affordable, reliable, sustainable and modern energy for all" [14]. It is unlikely that all renewable energy potential with current state-of-the-art technologies will supply energy demand, but it provides new opportunities for transition to low-carbon development without hindering economic growth and spillover effects [15].

The main objective of this study is to investigate contributions of renewable energy sources in achieving Turkey's INDC targets. In the scope of this study, Turkish national climate and energy policy frameworks, INDC, targets on renewable energy and electricity demand projections, costs of scenarios of BaU and INDC, and opportunities for carbon pricing instruments are analysed. The findings and results of the study could assist the policy makers in monitoring and reporting of CO_2 emissions for national communications, biannual reports to the UNFCCC and updating next cycle of Turkey's progressive INDC for the global stocktake process of the Paris Agreement.

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Table 1
INDCs and respective renewable energy policies.

	Target	Renewable energy linkages
The USA	Reducing its GHG emissions by 26%–28% below its 2005 level in 2025 and to make best efforts to reduce its emissions by 28%.	Cutting carbon pollution from new and existing power plants in line with Clean Air Act.
The EU	At least 40% domestic reduction in GHG emissions by 2030 compared to 1990.	Domestic legally binding legislation are already in place for the 2020 climate and energy package.
China	Peaking of CO_2 emissions around 2030, to lower CO_2 emissions per unit of GDP by 60–65% from the 2005 level.	Increasing the installed capacity of wind power 200 GW, solar power with 100 GW and the utilization of thermal energy reaching 50 million tons coal equivalent by 2020.
Brazil	Reducing GHG emissions by 37% below 2005 levels in 2025 and by 43% below 2005 levels in 2030.	Expanding the use of wind, biomass and solar 23% by 2030.
Turkey	Up to 21% reduction in GHG emissions from the BaU level by 2030.	Utilizing solar power to 10 GW until 2030, wind power to 16 GW until 2030, full hydroelectric potential.

This article is organized as follows: Section 2 overviews literature review of Turkey's energy and climate policy. Section 3 presents data and explains methodology. Results and findings are summarized in Section 4. Section 5 has discussions on results, challenges and opportunities. Last section concludes with recommendation on the INDC targets of Turkey.

2. Literature review

INDCs which include emission reduction targets of countries and reflect their national circumstances, have been submitted before the adoption of the Paris Agreement [16]. The common priority among the submitted INDCs is to stimulate the usage of renewable energy sources [17]. This is also in line with the energy system reform and the transition to low carbon development as recognized in the Article 4.19 of the Paris Agreement [18]. Table 1 summarizes a few major emitters' INDCs and related renewable energy policies and targets.

The European Union (EU) commits to reduce its projected emissions by 40 per cent in 2030 compared to 1990 level. The USA and Brazil submitted their INDCs having similar approach. The former will reduce its emissions of the year 2025 by 28 per cent from 2005 levels, and the latter will reduce its emissions of the year 2030 by 43 per cent from 2005 levels. It is expected that China will reach its emission peak by 2030 and reduce its emission intensity by 65 per cent from 2005 levels. As highlighted, EU as a climate policy frontier and China as the largest emitter underline renewable energy in their INDCs.

EU, both the climate leader in the negotiations and the frontier to promote the use of renewable energy, submitted its INDC in early 2015 [5]. In line with the de-carbonization objective of the EU, the renewable energy share will increase to 27 per cent by 2030 and EU will aim to change structural energy system such as electrification of transport, high deployment of renewable energy in industry, housing and electricity generation [5]. The other example is China that announced its INDC focusing on power sector and low-carbon development through increasing the share of renewable energy sources up to 20 per cent by 2030 [6,19]. The main drivers of China's emission mitigation are energy efficiency and renewable energy [20].

Turkey's INDC is similar to other countries in terms of renewable energy. Turkey has established policy frameworks for energy and climate change. Electricity Market and Security of Supply Strategy, Climate Change Strategy Paper and Climate Change Action Plan, National Renewable Energy Action Plan (NREAP) have targets on increasing share of renewable energy sources. Explicitly, Electricity Market and Supply Security Strategy sets out targets on achieving 30 per cent usage of renewable energy sources in electricity generation by 2023 [21]. This target is in line with Climate Change Strategy Paper for limiting CO_2 emissions from electricity generation. Turkey provides enabling environment for achieving this target. Legislation is developed and introduced renewable energy supports mechanisms such as Feed-in Tariffs (FiTs), competitive bidding and obligation to purchase electricity from renewable energy sources. For example, The Law on the Utilization of Renewable Energy in Electricity Generation established renewable energy support mechanisms in 2005 [22]. This law was updated in 2011 according to the level of progress in utilization of renewable energy sources [23,24]. The amended Law provides higher tariffs, increases the scale of unlicensed projects, extends the guarantee period to ten years and differentiates tariffs according to various sources [24]. Besides, commissioning deadline for renewable energy projects is extended from 2015 to 2020, and local content premium is included to accelerate research, development and deployment of renewable energy technologies throughout the country [23]. However, renewable energy support mechanisms particularly FiTs are still required to be differentiated in terms of scales and location of the projects. As a result of this amendment, utilization of renewable energy sources increased from 58,120 to 87,263 GWh between 2010 and 2017 [25]. Solar, wind and geothermal energy generation significantly increased and reached 2889, 17,903 and 6127 GWh, respectively. Although, local content premium embodied in FiTs promotes the improvement in domestic procurement, deployment of least-cost technology options and encouraging research and development investment within private sector [23,26], providing local content premium in renewable energy projects is a challenge for the multi-lateral trade agreements and tariffs.

In addition to FiTs, competitive bidding as another support mechanism was introduced in 2017. Under the framework of competitive bidding, Renewable Energy Source Areas (RESAs) were developed for solar and wind sources. In this context, the tender of a solar power plant with the capacity of 1000 MW was completed in *Karapinar RESA* and a manufacturing and research and development (R&D) centre with the annual production capacity of 500 MW will be established in this RESA. Similarly, 1000 MW wind power capacity has been allocated for wind RESA and wind turbine manufacturing and R&D centre with the annual production capacity of 400 MW will be established in *Province of Konya*. Even though installation of large scale of renewable energy power plants and low bidding prices have advantages on utilization of renewable energy, participation opportunities of small and medium scale investors and their competitiveness might be discouraged in these schemes.

In terms of climate policy framework, multilateral environmental agreements such as the UNFCCC and the Kyoto Protocol, and the National Climate Change Strategy and Action Plan play a crucial role in the utilization of renewable energy sources. Turkey as a developing country has been participating climate change negotiations since the beginning of Intergovernmental Negotiating Committee. Since Turkey is a member of the OECD, its name was included both Annexes of the UNFCCC namely Annex I and Annex II. However, Turkey is neither a developed country to provide finance to non-Annex I countries in the UNFCCC nor an industrialized country to have an emission reduction target because of the historical responsibility [27]. Turkey tried to be deleted from both annexes of the UNFCCC. However, its name was deleted from only Annex II and its special circumstances which defined and recognized that Turkey is different than other Annex I countries in

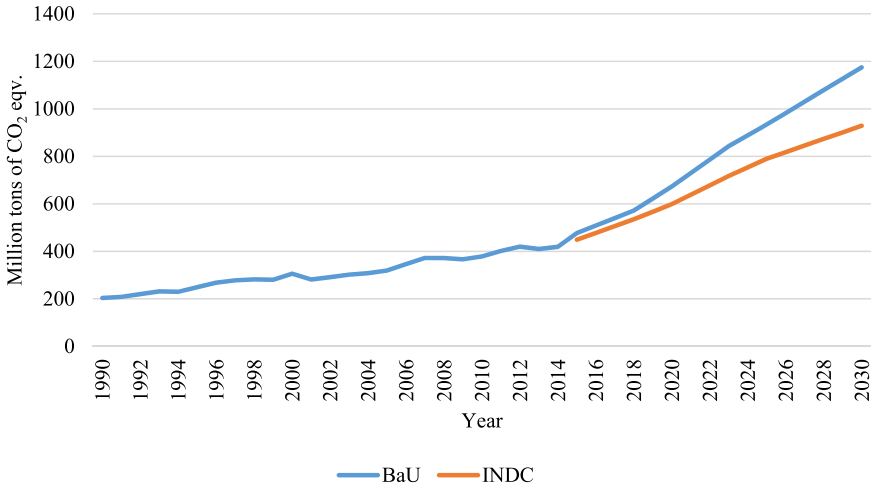

Fig. 1. Turkey's GHG Emission Projections in the INDC [31].

the UNFCCC [28]. Under these conditions Turkey ratified the UNFCCC and the Kyoto Protocol in 2004 and 2009, respectively [29]. Throughout negotiations of the Paris Agreement, Turkey tried to clarify its position as a developing country without referring to Annex I position in the UNFCCC. However, in the Paris Agreement, there was no reference to countries having special circumstances [30]. Therefore, it is still not clear that Turkey shall or should or may have quantified emission reduction target in other words absolute emissions reduction. Under this concern, Turkey signed the Paris Agreement in April 2016, but has not ratified the Agreement yet. Through INDC of Turkey, it announces its contribution as a deviation from BaU projections up to 21 per cent by 2030 [31]. Turkey significantly highlights renewable energy targets and their role in achieving INDC target. Fig. 1 shows that Turkey's INDC which covers energy, industrial processes, transportation, land use, land use change and forestry, agriculture and waste sectors [31]. According to BaU, GHG emissions are expected to reach 1175 million tons of CO_2 equivalent in 2030. Throughout the implementation of policies in the INDC, GHG emissions could be reduced to 929 million tons of CO_2 equivalent, by 2030. Except targets on renewable energy, the INDC did not provide any quantitative targets and references in other sectors. Additionally, there is no investigation of total or additional costs of emissions reduction and cost-benefit analysis of INDC target of Turkey.

The main challenge in the Turkish energy and climate policy is to secure energy supply with increasing energy demand, decrease dependency on imported energy technologies and reduce CO_2 emission [8,32]. According to projections, Turkey's emissions will continue to increase and it is very unlikely that emissions will peak by 2030 [31]. Because of this, Turkey has not committed any absolute emission reduction in other words Turkey has not been referring any base year emission level such as the year of 1990. The government wants to link emission reduction intention via reaching renewable energy targets [26]. Turkey can use its considerable renewable energy potential, so there will be still room to much more reduction in emission intensity of the electricity generation sector. Since electricity generation sector is the most emission intensive one due to high dependence on fossil fuels in electricity mix [24,32], introducing renewable energy sources can play a key role for mitigation of CO_2 emissions and transition to decarbonized energy system [32–34].

3. Data and method

In this study, quantitative and qualitative data have been gathered for the analysis of contribution of renewable energy sources in tackling climate change, particularly in emissions reduction. Various electricity generation data such as projections for electricity generation, national targets for the share of renewable energy sources, capacity factors of primary energy sources and their related technologies, CO_2 emissions factors for fossil fuel based power plants and levelized cost of electricity generation (LCOE) have been used.

Table 2 presents electricity generation according to primary energy sources. Since 1990, Turkey's electricity generation and installed capacity have been increased with the average rates of 6.3 and 6.2 per cent, respectively. Total electricity generation in Turkey reached 297,278 GWh in 2017 [25]. Hydropower, which has the highest installed capacity among renewable energy sources, has 27,231 MW installed capacity in 2017. Other renewable energy sources such as wind, solar and geothermal reached 6516 MW, 3420 MW and 1063 MW installed capacity, respectively [25]. Electricity generation from renewable energy sources was 29 per cent of total generation, so this ratio is slightly below the government target (30 per cent) for renewable energy.

Fig. 2 presents the total GHG emissions, electricity generation and CO_2 emissions from electricity generation, Turkey's total GHG emissions and CO_2 emissions from electricity generation were 496.1 and 144.6 million tons of CO_2 equivalent in 2016 respectively [35]. Since 1990, total emissions have increased by 135 per cent and the share of emissions from electricity generation increased from 18 to 29 per cent between 1990 and 2016 [35]. Although, emission intensity of this sector slightly declined from 0.643 to 0.527 t CO_2 emission per MWh in the last 26 years, it is possible that Turkish electricity generation sector will follow a trend towards low carbon energy when more renewable energy projects are implemented.

Due to economic and population growth, industrialization and urbanization, Turkey's electricity demand will continue to rise [24]. Turkish Government conducted three electricity generation projections namely Low, Reference and High Scenarios. By 2030, electricity demand will range between 468 and 592 TWh (Table 3). Annual growth rates of Low, Reference and High Scenarios are 3.5, 4.2 and 5.3 per cent respectively.

Turkey is willing to utilize renewable energy as much as possible [26]. In order to supply electricity demand and reach renewable energy target, the government updates its energy legislation, targets and improving renewable energy support mechanism to utilize significant renewable energy potential in solar, wind, geothermal and hydro [24]. It is estimated that the economic potential of hydro, wind and solar power to be in the range of 43,000 MW, 48,000 MW and 50,000 MW, respectively [23,37]. In terms of geothermal, Turkey uses only 10 per cent of economically feasible geothermal fields [24]. Similarly, Turkey has significant solar potential but solar capacity with under operation is not adequate and conservative. Table 4 summarizes planned and adopted renewable energy targets of Turkish electricity sector [24].

Table 2
Electricity generation profile of Turkey, GWh [25].

	Hydro	Geothermal	Wind	Solar	Biomass	Total of Renewable	Total	Share(%)
2000	30,879	76	33	–	174	31,161	124,922	25
2001	24,010	90	62	–	188	24,350	122,725	20
2002	33,684	105	48	–	134	33,970	129,400	26
2003	35,330	89	61	–	86	35,565	140,581	25
2004	46,084	93	58	–	83	46,318	150,698	31
2005	39,561	94	59	–	45	39,759	161,956	25
2006	44,244	94	127	–	73	44,538	176,300	25
2007	35,851	156	355	–	109	36,471	191,558	19
2008	33,270	162	847	–	154	34,433	198,418	17
2009	35,958	436	1495	–	264	38,153	194,813	20
2010	51,796	668	2916	–	347	55,727	211,208	26
2011	52,339	694	4724	–	364	58,121	229,395	25
2012	57,865	899	5861	–	609	65,234	239,497	27
2013	59,421	1364	7558	–	893	69,235	240,154	29
2014	40,645	2364	8520	17	1094	52,641	251,963	21
2015	67,146	3425	11,653	194	1263	83,680	261,783	32
2016	67,231	4819	15,517	1043	1659	90,268	274,408	33
2017	58,219	6128	17,904	2889	2124	87,263	297,278	29

In order to estimate electricity generation of renewable energy targets, as indicated by the installed capacity in Table 4, annual electricity generation potential is required. Capacity factor (CF) for each renewable energy source is required. These factors are defined in Equation-1 to estimate average annual electricity generation [38]:

$$CF = \frac{TotalAnnualElectricityGeneration(MWh)}{TotalInstalledCapacity(MW) \times 24hours \times 365days} \quad (1)$$

It is known that Turkey has announced renewable energy targets as planned installed capacity of renewable energy sources. Since different types of plants have different capacity factors, it is essential to gathered capacity factor values for each renewable energy sources [38]. To find total annual electricity generation, each installed capacity of renewable energy source is multiplied with respective capacity factor and converted to one year amount. As Turkey sets its renewable energy targets directly for 2017, 2019, 2023 and 2030 values of planned installed capacity of the intermediate years are interpolated. Besides, Turkey plans to introduce *Akkuyu* Nuclear Power Plant with 4800 MW installed capacity. The first unit with 1200 MW will be established in 2023 and each of other three units will be completed in 2024, 2025 and 2026 respectively [39]. After introducing all installed capacities with their respective electricity generation into the total electricity demand projection, the remaining parts of required electricity generation are allocated according to 2017 primary energy sources mix of Turkey's electricity supply table.

After allocation of all primary energy sources including fossil fuels and renewable energy sources, electricity demand is supplied. As the

Table 3
Electricity demand projections, TWh [36].

Years	Low	Reference	High
2018	301.51	304.43	307.21
2019	315.81	319.46	323.79
2020	328.41	334.98	343.24
2021	341.04	350.70	363.44
2022	354.16	367.26	384.85
2023	367.88	384.64	407.89
2024	381.81	402.31	431.66
2025	396.14	420.51	456.47
2026	410.53	439.17	482.26
2027	424.97	457.88	508.61
2028	439.50	477.04	535.94
2029	454.14	496.50	564.13
2030	468.40	515.96	592.84

Table 4
Renewable energy targets for electricity generation, MW [24].

	2017	2019	2023	2030
Hydro	27,700	32,000	34,000	34,000
Wind	9500	10,000	20,000	20,000
Geothermal	420	700	1000	1000
Solar	1800	3000	5000	5000
Biomass	540	700	1000	1000

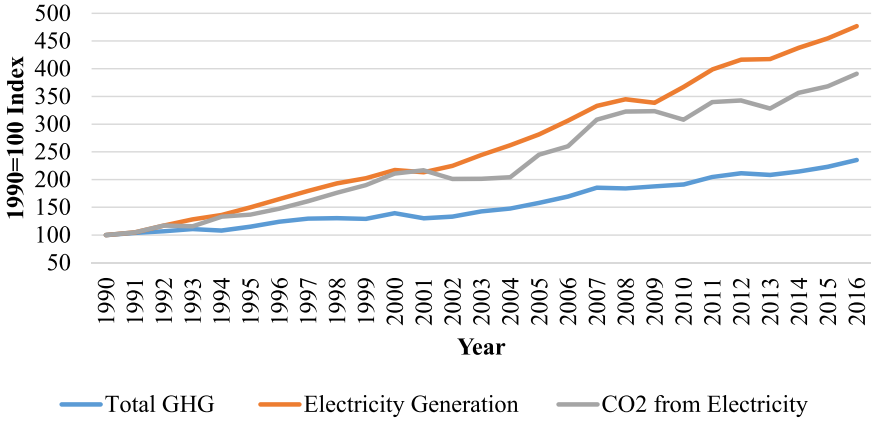

Fig. 2. Total GHG emissions, CO_2 emissions from electricity and electricity generation.

Table 5
Capacity factors (CF) for renewable energy sources [40].

	Hydro	Wind	Geothermal	Solar	Biomass
CF	0.39	0.33	0.74	0.25	0.55

Table 6
Fuel specific CO_2 emission factors, ton CO_2 per GWh [42].

	Coal	Lignite	Fuel oil	Diesel	LPG	Naphtha	Natural gas
EF	1018	1080	755	805	413	461	374

CO_2 emissions are sourced from fossil fuels only, the CO_2 emissions resulting from the utilization of each fossil fuels types are calculated by using fuel specific emission factors [41,42]. CO_2 emissions are calculated according to Equation-2, using the listed country specific CO_2 emission factors (EF) for fossil fuels listed in Table 6.

$$CO_2(tons) = EF(tons/GWh) \times GeneratedElectricity(GWh) \quad (2)$$

Reducing CO_2 emissions through replacing fossil fuels with renewable energy sources and technologies might lead to additional costs for electricity generation. In order to compare and analyse impacts of transition to greener technologies in electricity generation sector, cost estimation and comparison of various renewable energy sources and technologies are conducted with levelized cost of electricity (LCOE) tools. Accordingly, the unit costs of renewable energy power plants over their life time are listed in Table 7 [43].

LCOE of each primary energy sources including fossil fuels and renewable energy sources is multiplied with annual electricity generation amount. Therefore, total costs are estimated for each scenario annually.

4. Results

As presented in Table 2, there are mainly three scenarios based on electricity demand growth rates. Scenarios are differentiated according to contribution of renewable energy sources as implied in Turkey's INDC, so they called Low-INDC, Reference -INDC and High-INDC scenarios. Scenarios result in total CO_2 emissions, costs and impacts on INDC target. Following Tables 7–9 present these three scenarios with BaU and INDC cases.

INDC cases are based on renewable energy targets in Turkey's INDC, and presents electricity supply projections and related CO_2 emission trajectories by 2030. The INDC scenario includes utilization of economically feasible part of hydropower, wind with 16,000 MW capacity and solar with 10,000 MW by 2030 (Table 5). Besides, as highlighted in the INDC, nuclear power plant and its units will gradually operationalized between 2023 and 2030, and nuclear power capacity will reach 4800 MW by 2030.

Table 8 presents results of low growth scenario. Low-BaU and Low-INDC are two sub scenarios. Total CO_2 emissions in Low-BaU and Low-INDC reach 187.54 and 148.67 million tons respectively. Emission reduction reaches 38.87 million tons of CO_2 emissions by 2030, and maximum emissions reduction occurs in 2023 with an amount of 58.42 million tons of emissions. Total costs of electricity generation vary between 18.37 and 30.59 billion USD in Low-BaU, and 18.37 and 31.80 billion USD in Low-INDC. Substituting renewable energy sources and technologies resulst in additional costs reaching 1.21 billion USD by 2030 and these costs are maximum amount in 2023 as 1.46 billion USD. Average costs of emission mitigation in Low-INDC case are between 6.82 and 31.13 USD per ton of emission. Contribution to emission reduction target of Low-INDC case is significant. Although this contribution is decreasing towards 2030, it provides 72 per cent of Turkey's INDC annual emission reduction in 2019. By 2030, this contribution decreases to 16 per cent.

Table 7
Levelized cost of electricity in Turkey, USD per MWh [43].

Coal	Natural Gas	Waste	Hydro	Geothermal	Solar	Nuclear
62.33	53.9	96.98	54.41	90.69	129.57	115.21

Table 9 presents results of Reference growth scenario. Reference-BaU and Reference-INDC are two sub scenarios. Total CO_2 emissions in Reference-BaU and Reference-INDC reach 210.58 and 180.95 million tons respectively. Emissions reduction reaches 29.62 million tons of CO_2 emissions by 2030, and maximum emissions reduction occurs in 2023 with an amount 55.16 million tons of emissions. Total costs of electricity generation vary between 18.55 and 33.49 billion USD in Reference-BaU and 18.55 and 34.58 billion USD in Reference-INDC. Additional cost of substituting renewable energy sources and technologies reaches 1.09 billion USD by 2030 and is maximum amount in 2023 as 1.42 billion USD. Average costs of emission mitigation in Reference-INDC case are between 6.62 and 36.81 USD per ton of emission. Contribution to emission reduction target of Reference-INDC case is significant. Although this contribution is decreasing towards 2030, it provides 71 per cent of total Turkey's INDC in 2019. By 2030, this contribution decreases to 12 per cent.

Table 10 presents results of low growth scenario. High-BaU and High-INDC are two sub scenarios. Total CO_2 emissions in High-BaU and High-INDC reach 247.82 and 233.15 million tons respectively. Emissions reduction reaches 14.68 million tons of CO_2 emissions by 2030, and maximum emissions reduction occurs in 2023 with an amount of 50.64 million tons of emissions. Total costs of electricity generation vary between 18.72 and 38.17 billion USD in High-BaU, and 18.72 and 39.07 billion USD in High-INDC. Additional cost of substituting renewable energy sources and technologies reaches 0.90 billion USD by 2030 and is maximum in 2023 as 1.36 billion USD. Average costs of emission mitigation in High-INDC case is between 6.36 and 61.13 USD per ton of emission. Contribution to emission reduction target of High-INDC case is significant. Although this contribution is decreasing towards 2030, it provides 69 per cent of total Turkey's INDC in 2019. By 2030, this contribution decreases to 6 per cent.

5. Discussions

Turkey meets its INDC targets providing that it harmonizes energy policy with climate policy. Policy framework and legislation including renewable energy support mechanisms such as FiTs, competitive bidding and purchasing guarantee are adopted to utilize renewable energy sources. For the first time in 2017, Turkey started to use competitive bidding for two 1000 MW for large scale install capacity of wind solar projects. Both FiTs and competitive bidding with purchasing guarantee provide incentives to research, development, demonstration and deployment of renewable energy projects [24]. Since costs of renewable energy technologies are higher than conventional fossil fuel technologies, it is essential to support renewable energy technologies in research, development, demonstration and deployment phases [8]. Both projects with R&D centres will contribute to development of state-of-the-art renewables energy technologies. Through these supports, Turkish Government encourages low carbon technologies and takes measures for concerns of early stages of development against to 'valley of death' [23,44,45]. When these technologies are widely commercialized, there will be considerable potential for the transition to low-carbon development [8].

Besides renewable energy projects, non-fossil fuel based energy projects such as nuclear power plants will be in operation by 2023. First phase of *Akkuyu* Nuclear Power Plant with 1200 MW (4800 MW total) installed capacity will be available by 2023, and each 1200 MW of second, third and last phases of the plant will start generating electricity in 2024, 2025 and 2026, respectively [39].

Table 8
Results of low growth scenario.

Low growth scenario								
	Low-BaU		Low-INDC		Reduced emissions	Additional costs	Ave. cost of Red. emissions	Contribution to INDC
	Emissions	Costs	Emissions	Costs				
2018	146.07	18.37	146.07	18.37	0.00	0.00	0.00	0%
2019	153.00	19.24	113.01	19.56	39.98	0.31	7.85	72%
2020	159.10	20.01	117.46	20.30	41.63	0.28	6.82	56%
2021	165.22	20.78	119.56	21.29	45.66	0.50	11.01	50%
2022	171.57	21.58	121.98	22.30	49.59	0.72	14.54	46%
2023	168.38	22.93	109.96	24.39	58.42	1.46	25.04	46%
2024	165.28	24.29	109.57	25.72	55.71	1.43	25.63	41%
2025	162.38	25.67	109.45	27.07	52.92	1.39	26.29	37%
2026	159.50	27.06	109.38	28.42	50.12	1.36	27.04	30%
2027	166.50	27.94	119.18	29.26	47.32	1.32	27.88	26%
2028	173.54	28.83	129.05	30.11	44.49	1.28	28.83	22%
2029	180.63	29.72	138.98	30.97	41.64	1.25	29.91	18%
2030	187.54	30.59	148.67	31.80	38.87	1.21	31.13	16%

Results of different electricity supply scenarios come up with different emission trajectories. Total required emission reduction in Turkey's INDC is 1798 million tons of CO_2 equivalent between 2018 and 2030. This reduction includes all sectors and other GHGs. Increasing the share of renewable energy in electricity generation sector can mitigate cumulative 566, 511 and 428 million tons of CO_2 emissions in Low-INDC, Reference-INDC and High-INDC Growth scenarios, respectively (Fig. 3). Renewable energy will significantly contribute to meet Turkey's INDC targets. However, after 2023, quantified emissions reduction via substituting renewable energy sources will decrease. There might be imbalance between energy supply and demand projections [23,24]. In this regard, renewable energy attracts more importance to solve imbalance and insufficient supply capacity. Therefore, the government should commit to increase renewable energy utilization and increase its share in energy mix [46]. Addition of new installed capacity of renewable energy is essential to meet the targets of INDC.

Between 2018 and 2030, total additional costs of Low-INDC, Reference-INDC and High-INDC are 12.52, 11.80 and 10.73 billion USD, respectively. Due to having the highest total emission reduction, Low-INDC scenario has the highest cost among all scenarios. Additional costs per reduced emissions are presented in Fig. 4. Low-INDC case has the lowest unit cost for emissions reduction. Although, this scenario has the highest total cumulative costs for the INDC period, larger emissions reduction for this case leads to low unit costs.

Additional costs of mitigation from fossil fuel technologies to low carbon technologies can be minimized by putting a price on carbon [47,48]. Carbon pricing as a market based instruments enables countries to internalize this externality [49]. Carbon trading is one of the main carbon pricing instruments. Countries have experience in emission trading schemes at national and regional level such as European Emission Trading System (EU-ETS). The EU-ETS provides cost-effective emissions reduction for the EU member states [50]. In 2018 carbon prices vary between 1 and 139 USD per ton of emission, this range for EU-ETS is 7–16 USD per ton [50]. These ranges might increase in the implementation period of the Paris Agreement. Average costs of emissions reduction in INDC scenarios of this study can be reduced by integration of global or regional carbon pricing initiatives such as EU-ETS. Additionally,

the Article 6 of the Paris Agreement namely Sustainable Development Mechanism and internationally transferred mitigation outcomes provide new opportunities for all countries to participate global carbon pricing [51].

Besides, Turkish INDC highlights the necessity of external financial resources, policy supports and guarantees while setting out renewable energy targets in order for the sustainability of renewable energy technologies. When policy environment including financial opportunities and legislative framework is sustained, deployment of renewable energy will help to achieve INDCs in a cost effective manner [52]. Besides, environmentally harmful and fossil fuel-dependent technologies can be eliminated supporting the transition to low- carbon development [6,32]. To be coherent with all energy strategy papers and policies, the share of renewable energy in the energy mix should be at

Table 9
Results of reference growth scenario.

Reference growth scenario								
	Reference-BaU		Reference-INDC		Reduced emissions	Additional costs	Ave. cost of Red. emissions	Contribution to INDC
	Emissions	Costs	Emissions	Costs				
2018	147.48	18.55	147.48	18.55	0.00	0.00	0.00	0%
2019	154.76	19.47	115.49	19.77	39.27	0.30	7.76	71%
2020	162.28	20.41	121.92	20.68	40.36	0.27	6.62	55%
2021	169.90	21.37	126.12	21.85	43.78	0.48	10.93	48%
2022	177.92	22.38	130.88	23.07	47.04	0.69	14.62	43%
2023	176.49	23.95	121.34	25.37	55.16	1.42	25.75	44%
2024	175.21	25.54	123.49	26.91	51.72	1.38	26.60	38%
2025	174.18	27.16	126.00	28.49	48.18	1.33	27.61	33%
2026	173.38	28.81	128.82	30.09	44.55	1.28	28.80	27%
2027	182.44	29.95	141.52	31.18	40.92	1.24	30.22	22%
2028	191.72	31.12	154.53	32.30	37.19	1.19	31.95	18%
2029	201.15	32.30	167.74	33.44	33.41	1.14	34.10	15%
2030	210.58	33.49	180.95	34.58	29.62	1.09	36.81	12%

Table 10
Results of high growth scenario.

High growth scenario								
	High-BaU		High-INDC		Reduced emissions	Additional costs	Ave. cost of Red. emissions	Contribution to INDC
	Emissions	Costs	Emissions	Costs				
2018	148.83	18.72	148.83	18.72	0.00	0.00	0.00	0%
2019	156.86	19.73	118.43	20.02	38.43	0.29	7.64	69%
2020	166.28	20.92	127.53	21.16	38.75	0.25	6.36	52%
2021	176.07	22.15	134.77	22.59	41.30	0.45	10.81	45%
2022	186.44	23.45	142.82	24.10	43.62	0.64	14.76	40%
2023	187.76	25.37	137.12	26.73	50.64	1.36	26.90	40%
2024	189.43	27.33	143.41	28.63	46.01	1.30	28.30	34%
2025	191.60	29.35	150.41	30.59	41.19	1.24	30.10	29%
2026	194.25	31.43	158.08	32.61	36.18	1.18	32.48	22%
2027	207.02	33.04	175.96	34.15	31.05	1.11	35.71	17%
2028	220.26	34.70	194.52	35.74	25.74	1.04	40.41	13%
2029	233.91	36.42	213.66	37.39	20.26	0.97	47.85	9%
2030	247.82	38.17	233.15	39.07	14.68	0.90	61.13	6%

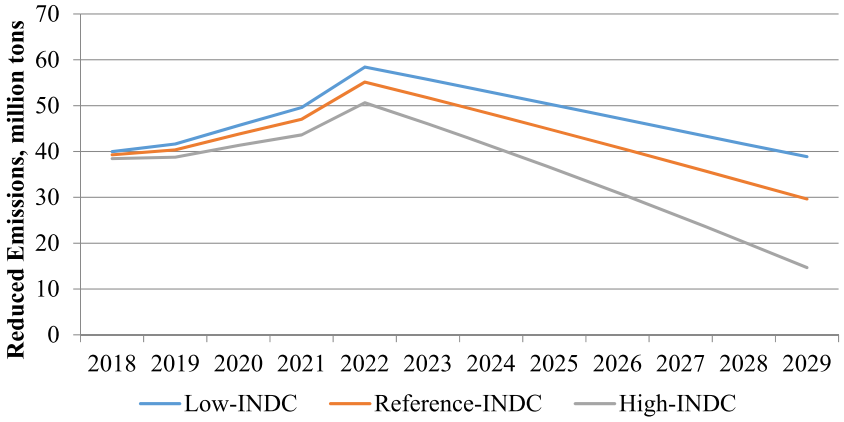

Fig. 3. Comparison of scenarios for reduced emissions.

least 30 per cent for Turkey. When rising demand and environmental challenges are concerned, more renewable energy projects should be completed and gone under operation.

6. Conclusion

Turkey, as an emerging economy and upper-middle income country, submitted its INDC with renewable energy targets. According to the Paris Agreement, countries have already started reviewing, updating and upgrading their targets in INDCs. Transition to low-carbon development gained some momentum after the adoption of the Paris Agreement. Renewable energy is recognized as a mainstream element to achieve countries INDCs, a decoupling tool between carbon intensity and economic growth and the source of new decent jobs.

This paper analysed contribution of renewable energy sources to meet Turkey's targets in its INDC. Three main scenarios namely Low, Reference and High Growth and their INDC cases conclude that utilization of renewable energy potential of Turkey can enable to achieve

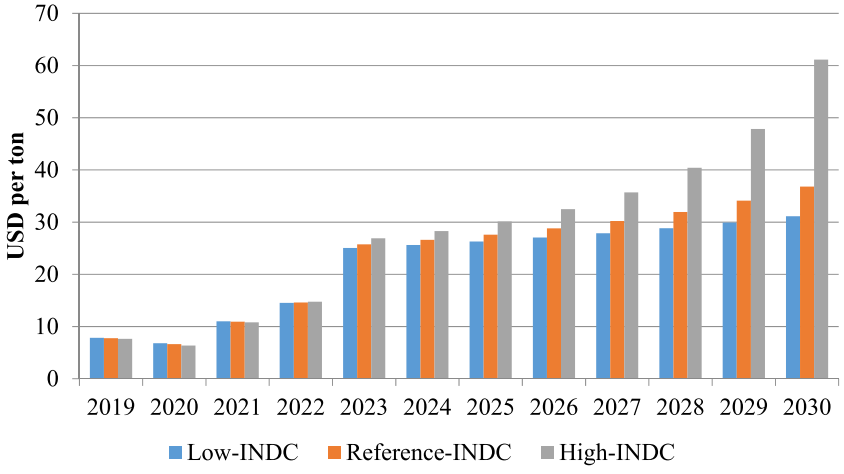

Fig. 4. Additional costs per reduced emissions, USD per ton of CO_2 emissions.

emission target of Turkey's INDC. Low-INDC, Reference-INDC and High-INDC scenarios can provide 32, 29 and 24 per cent of cumulative emission reduction for the targets announced in Turkey's INDC. Nevertheless, all scenarios have some challenges such as growing electricity demand, decreasing the share of renewable energy sources among primary energy sources to generate electricity and rising average abatement costs between 2018 and 2030. Therefore, new and additional renewable energy projects should be planned for the INDC period.

In conclusion, renewable energy has a significant role in achieving INDC targets for Turkey and it is also prioritized in other countries' INDCs. It is expected that INDCs will need to be reviewed during the global stocktaking of the Paris Agreement. For this reason, before the global stocktaking and peer - country review process start, Turkey should update its INDC with new renewable energy targets.

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